Anaerobic digestion of swine manure: Sung-Hwan farm-scale biogas plant in Korea


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Abstract
In order to increase the use of biogas plants in Korea, a farm-scale biogas plant with a working volume of 200 m$^3$ was constructed at the pig farm in Sung Hwan, Korea as a demonstration project supported by the Korean government. This plant mainly consists of an anaerobic digester processing daily 10 m$^3$ pig manure and a dual-fuel engine-generator to produce heat and electricity. Digestion takes place in a semi-continuous, single stage, completely stirred anaerobic digester under mesophilic temperatures with maximum 0.8°C deviation per day from the setting temperature of 35°C. The digester was constructed as cylindrical flat-bottomed tanks instead of general conical bottoms. But it did not cause any serious mixing trouble. The results of solids profiles and temperature profiles inside the digester showed very small variations, which mean adequate mixing performances. During anaerobic digestion, 55% of volatile solids (VS) reduction in average was stably achieved. However no further VS reduction was occurred due to its inherent non-readily biodegradable materials. The average biogas yield was 0.70 m$^3$ per kg of added volatile solids. The biogas composition was relatively constant for the entire run with the 68-73% methane(V/V) and 27-30% carbon dioxide(V/V). The produced biogas was effectively used in a dual-fuel engine-generator to produce heat and electricity.

Key words anaerobic digestion, biogas, methane, swine manure

Introduction
Anaerobic digestion is considered as one of the most cost-effective alternatives for high strength wastewaters like swine manure. Especially, biogas plant processing swine manure have acted as an income source at the pig farms in European countries since it produces renewable energy (methane) and valuable digested residues that can be used as liquid fertilizer and soil conditioner (Bonmati et al., 2001; van Lier et al., 2001). In addition, Angelidaki and Ahring (2000) suggested the biogas plant could be economically viable, only if special taxation measures economically favor energy from biogas, compared to energy from conventional fossil fuels. However, it is rare at the pig farms in Korea. The major reasons are improper processes design and operation failures, insufficient government supports, and insufficient arable land to utilize the digested manure. In recent, Korean government has a plan to produce 2% electricity from renewable sources by 2010. It has the option
of encouraging renewable energy with a fixed high price for electricity. In this situation, we have operated a farm-scale biogas plant to investigate the feasibility and operational criteria of economic digesters as an income source for pig farms in Korea. This biogas plant has been in successful operation since 2000. Therefore, the purpose of this work is to present the practical experiences and operational results of the plant.

**Material and Methods**

**Biogas plant description**

As shown in Figure 1, this plant mainly consists of an anaerobic digester (20 day retention time), which processes daily 10m$^3$ pig manure and a dual-fuel engine-generator. Digestion takes place in a semi-continuous, single stage, completely stirred anaerobic digester under mesophilic temperature of 35°C. The digester was constructed as cylindrical flat-bottomed tank with a depth/width ratio close to 1 due to the economic installation instead of conical bottoms in the many early anaerobic digesters. An adequate mixing is significantly important when digesting swine manure in particular due to its high content of sand. Therefore, among many mixing systems, gas recirculation with draft tube and supplementary external recirculation pump were used together. The major advantage of this mixing system is the complete absence of any mechanical part inside the reactor. This eliminates potential problems of mechanical devices. For the purpose of digester heating, an external heat exchanger was used. The feed pump is interlocked with the sludge recirculation pump so that the latter operates whenever feed enters the heat exchanger. The inlet and outlet temperatures of the heat exchanger were monitored since the significant difference indicates the reduced heat transfer. The operation of this plant is fully automated.

**Figure 1. Process diagram of the farm-scale biogas plant**

An electricity generator adds significantly to the capital costs, but may be a more suitable way of
the energy usage if there is not a sufficient heat sink for the hot water. Consequently, in this plant, a dual fuel engine-generator was used to supply all energy demands on the plant, and the surplus of electricity and heat was planned being fed into the pig-breeding farms. It is rated at continuous 33kW, 380/220volt, 3-phase, 0.8 power factor, and 60Hz. This engine allows up to 90-50% substitution of biogas for diesel fuel. Produced heat is recovered by both the cooling water exchanger system and exhaust heat exchanger system.

**Digester start-up**

As swine manure does not contain sufficient methane bacteria to start the biological anaerobic digestion, seeding with fouled sewage sludge and cattle manure was done for rapid start-up. At first the empty reactor was filled in 20% of total net volume sewage sludge and 5% of cattle manure. It was heated to 25°C, then feeding was started by 20% of the designed quantity with a 1°C per day temperature increase until 35°C was reached.

**Feed characteristics**

The feed swine manure was quite diluted because the pig farm was newly installed for the research purpose and used lots of water to clean out the sheds. Most of all, Foot and Mouth disease during this period is the main reason of lots of cleaning-water usage. The pollutants concentrations (mg/L) of influent swine manure were varying in a large range; TS 3,750-40,800, VS 2,620-29,115, COD 4,540-44,800, SCOD 1,750-34,580, TN 500-3,561, TP 120-580, ammonia nitrogen 290-1,250, and alkalinity as CaCO₃ 1,742-7,882 mg/L, respectively. Swine manure was filtered by a screen to remove large particles prior to feeding into the digester.

**Analytical Methods**

A complete analytical characterization was carried out according to Standard Methods, during all the experiments. The methane production rates were estimated by analysis of the methane contents of the biogas. Methane in the biogas was analyzed by gas chromatography (HP 5890) with a flame ionization detector. In order to calculate theoretical biogas yield of feed, elemental analysis was conducted by EA 1110 elemental analyzer (CE Instruments, Italia).

**Results and Discussion**

**Strategic digester operation and monitoring**

Because of the temperature sensitivity of the methane forming bacteria, maintaining a constant digester temperature is inevitable. Therefore, the temperature of the digester inside ranged from 34.5-35.8°C with maximum 0.8°C deviation per day from the setting temperature of 35°C.

Many researchers suggested ammonia nitrogen is the main inhibitor during swine manure anaerobic
digestion (Angelidaki and Ahring, 1994; Hansen et al., 1998). Especially free-ammonia (NH$_3$) rather than ammonia (NH$_4^+$) is the real inhibitor. Free-ammonia concentration is strongly dependant on pH, ammonia nitrogen concentration, and temperature, but it depends more severely on pH. If pH falls below 6, free-volatile fatty acids become toxic to methane forming bacteria. Above a pH of 8, free-ammonia becomes toxic to methane forming bacteria. As shown in Figure 2, therefore, the pH of digester was kept mainly from 7.0 to 7.4, healthy environment for methane forming bacteria, in order to minimize the toxicity of both free-ammonia and free-volatile fatty acids. Alkalinity was maintained in the range of 2,966-6,606 mg/L as CaCO$_3$, which was quite enough to keep stable pH. In the swine manure digestion, not only imbalanced biological process but also physical hindrance such as scum and sediment formation should be very carefully monitored to protect process failures. Various methods, including solids concentrations profiles, temperature profiles, and VS/TS ratios, have been used to evaluate mixing performance. Samples were collected at 2.0m intervals of depth within the tank and analyzed for total solids concentration. The solids concentration did not deviate from the average concentration in the digester by more than 10% over the entire digester depth. Temperature at the top of the digester was only higher than the bottom by 0.5°C. These results indicate that the digester is under adequate mixing. Moreover the VS/TS ratio of digester sludge is an excellent indicator to determine the accumulation of inorganic matters inside the digester. As shown in Figure 3, the VS/TS ration was 0.56 during the entire run with little fluctuation. It means that no accumulation of grit was occurred and bacteria inside the digester are in stable condition. Consequently, these results indicate the used mixing system was fairly adequate for swine manure digester.

![Figure 2. Alkalinity and pH variation of anaerobic digester (□, digester alkalinity; ■, feed alkalinity; ○, digester pH; ●, feed pH)](image)

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Figure 3. TS, VS, and VS/TS ratio variation in anaerobic digester (□, VS/TS ratio; ○, digester VS; ●, digester TS)

**Digester performance**

The digestion performance of swine manure was stable based on the results from the process monitoring such as VS reduction, pH and alkalinity variation, COD reduction, and biogas production. The effluent COD which was measured after 30 minute settling in the normal operation of the digester was quite low from 420 to 6,700 mg/L (2,800 mg/L in average), even with fairly large fluctuations in feed COD concentration of 5,490-43,800mg/L. The VS reduction of 55% in average (37-78%) was stably achieved over a period of 400 days normal operation (Figure 4). However no further VS reduction was achieved due to its inherent hardly biodegradable materials.

Figure 5 shows the daily biogas production and input VS loading rates from June 2000 until October 2001. The varying input VS amount resulted in the significant fluctuations in the daily biogas production. The average biogas yield was 0.70 m³/kg VS added (0.47 CH₄ m³/kg VS). It is relatively higher than the normally achieved biogas yield from manure (0.2-0.25 CH₄ m³/kg VS) (Hansen et al., 1998; Hartmann et al., 2000). This result was thought because of the protein-rich feedstock, and long retention times of 40 days when 5 m³/d manure was fed because the produced swine manure was not reached the design capacity of 10 m³/d. From the elemental analysis of feed (C₁₄.₂₅H₂₈.₈₀O₄.₄₃NS₀.₀₃) conducted in three times, theoretical biogas and methane yields at STP condition were calculated as 1.12 L biogas/g VS destroyed, and 0.724 L CH₄/g VS destroyed respectively. Therefore the obtained biogas yield was about 63% of theoretical amount of feed.
Even though pH is a useful parameter of process stability, it is a very poor indicator in highly buffered substrates such as swine manure. Therefore, biogas production and the composition of the gas was monitored regularly since they are fairly sensitive indicators of stability at least when the amount and the composition of the feed remains constant. The obtained biogas composition was relatively constant throughout the operating period with the 68-73 vol % methane and 27-30 vol% carbon dioxide. This result means the process is in the stable operation.

In addition to its toxic properties H$_2$S is corrosive which can cause problems during combustion of the biogas. Therefore, ferric chloride was injected into the feed to remove H$_2$S as insoluble iron salts. As presented in Figure 6, this method was very effective in removing H$_2$S.
concentrations in the biogas down to 32 mg/m$^3$ in average was achieved. A dramatic increase on day 100 was caused by an accidental stop of ferric chloride dosing.

![Graph showing H$_2$S Gas (mg/m$^3$) vs. Time (days)](image)

**Figure 6. Hydrogen sulfide removals**

**Energy production**

The produced biogas was used in a dual-fuel engine-generator (33kW) to produce heat and electricity. At the designing biogas plant, we expected that the process itself might supply all energy demands of the plant. Furthermore, the surplus of electricity planned to be feed into the newly installed pig farms. However, the engine was run at only 20% of its power capacity since the new farms were not constructed due to the Food and Mouth dieses. This resulted in the low efficiency of electricity generation as shown in Figure 7. At this load, only 0.82 kWh of electricity was generated from the consumption of 1 m$^3$ biogas. But it could produce 2.1kWh when it was run at 100% load. In addition, produced biogas was not reached to the expected value due to the low input VS amount of the feed. This led the dual-fuel engine-generator to be run only for 2-12 hours a day (5 hours in average) in the daytime with the inspection of the operator. Consequently, the electricity produced from the generator occupied only about 32% of total electric need at the biogas plant. However, if the engine-generator will be run for 24 hours at its proper power load, it can produce enough electricity to provide for about 80-100 average homes.

![Graph showing Electricity Production (kWh) vs. Biogas Consumption (m$^3$)](image)

**Figure 7. Electricity generated vs. biogas consumed at different operational power loads on engine-generator**
During the operation of this plant the engine-generator required the most maintenance but it did not have any serious problems. Routine operation took approximately 1 hour per day. This includes the system inspection, pumping manure into the digester 3-5 times a day, starting and shut downing the biogas engine, checking gauges to measure biogas and electricity generation.

Conclusions
In spite of large fluctuations in pollutants concentrations and feed quantity, stable digestion performances were obtained with VS reduction of 55% and methane yield of 0.47 m³/kg VS added, respectively. Mixing results clearly demonstrated that combined use of both gas recirculation and external circulation pump is effective in a flat-bottomed digester treating swine manure. Even though engine-generator required the most maintenance during the operation of biogas plant, it was considered as a most suitable means of energy recovery. The overall results of this biogas plant were successful, and it obviously reveals that biogas plant can be considered as an effective process for energy recovery and pollution minimization of swine manure. Additionally the economic viability of biogas plant could be improved by using high biogas potential co-substrates such as fats, food wastes and residues from food industry, and many similar substances in addition to manure.

References